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DESIGN OF MULTI FUNCTION HHO SUPPLIER

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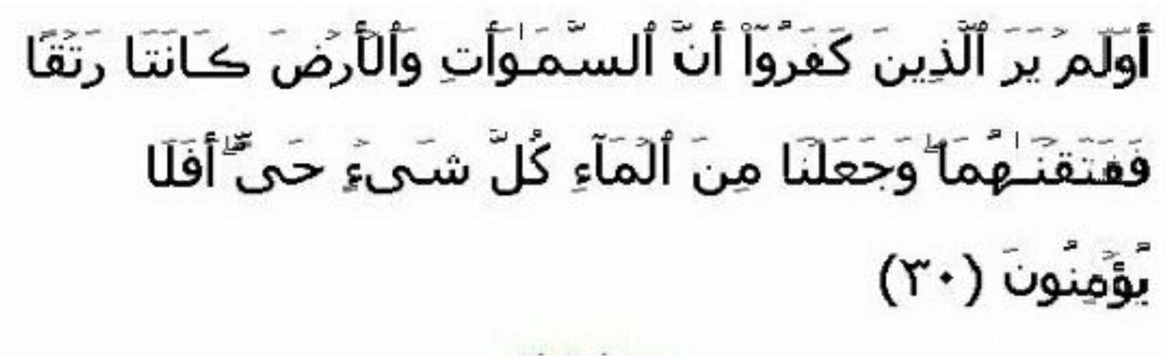

أَوَلَمْ يَرَ ٱلَّذِينَ كَفَرُوٓاْ أَنَّ ٱلسَّمَٰوَٰتِ وَٱلْأَرْضَ كَانَتَا رَتْقًا
فَفَتَقْنَٰهُمَا ۖ وَجَعَلْنَا مِنَ ٱلْمَآءِ كُلَّ شَىْءٍ حَىٍّ ۖ أَفَلَا
يُؤْمِنُونَ (٣٠)

سورة الانبياء (الآيه 30)

DEDICATIONS

This study is lovingly dedicated to our parents for their emotional and financial support, our brothers, our sisters and our friends whose has been constant source of inspiration for us. They have given us the drive and discipline to tackle any task with enthusiasm and determination. Without their love and support this project would not have been made possible.

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Abstract

Hydro-oxy gas or (HHO) it is a mixture gas between oxygen and hydrogen (33.3% oxygen and 66.6% hydrogen). This gas is used for different application in industrial, agricultural and domestic fields. The most commonly method to produce this gas is electrical electrolysis of water.

Our project aims to design multi purposes system to be used for cooking and welding and we achieved this by attached pressure control unit to control the amount of gas flow and interface unit to control the rate of gas production. Also our system consist monitor screen to monitor the system performance during the operation.

مستخلص

غاز الهيدروكسي هو غاز خليط بين الهيدروجين والاكسجين بنسب معلومة ، وله عدة استخدامات في القطاع الخدمي ، الصناعي والزراعي . يتم إنتاج هذا الغاز عبر التحليل الكهربائي للماء .

الهدف من البحث هو تصميم نظام يصلح للعديد من الإستخدامات و ذلك لاحتوائه على وحدة للتحكم في ضغط الغاز ونظام للتحكم في كمية انسياب الغاز من داخل المفاعل . يتم التعامل مع النظام بواسطة واجهة ادخال متصلة بشكل مباشر بنظام التحكم . كما يوجد شاشات عرض لمراقبة أداء النظام .

نظام امداد الطاقة يمكن أن يكون الشبكة القومية للكهرباء أو الطاقة الشمسية لانتاج الغاز بصورة تجعله ضمن مصادر الطاقة المتجددة والنظيفة .

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LIST OF SYMBOLS

F	Faraday constant (F), 96485 col mol-1
N	Number of moles of electrons for hydrogen
nO2	Number of moles of electrons for oxygen
P	Pressure in the cell (P = PO2 = PH2), ba
R	Universal gas constant, 8.31446 j/mol-k
T_O	Temperature at standard condition, 298K
T	Absolute temperature of cell, K
I	Total current applied on the cell, A
ρH2	Density of hydrogen molecule, 0.0899 kg m-3
ρO2	Density of oxygen molecule, 1.429 kg m-3
Go	Gibbs free energy, j mol-1
ΔGT	Gibbs free energy at temperature T
ΔH0	Change in enthalpy at standard temperature, j mol-1
ΔHT	Change in enthalpy with temperature, j mol-1
ΔS0	Change in entropy at standard temperature J mol-1K-1
ΔST	Change in entropy with temperature J mol-1K-1
ΔCP	Change in specific heat, J mol-1K-1
CP,h2	Specific heat of hydrogen gas, J mol-1K-1

CP,o2	Specific heat of oxygen gas, J mol-1K-1
SH2	Entropy of hydrogen, J mol-1K-1
SO2	Entropy of oxygen, J mol-1K-1
SH2O	Entropy of water, J mol-1K-1
Urev	Reversible cell voltage, V
UTH,T	Thermo-neutral voltage, V
αa,αc	Transfer coefficients of anode and cathode

CHAPTER ONE

INTRODUCTION

1.1 General concepts

HHO otherwise known as hydro-oxy or Browns Gas is the gas produced from splitting water into hydrogen and oxygen from electrolysis and allowing the gas to stay in a premixed state for use on demand without any need for storage system. In 1918 Charles Frazer, a North American inventor, designed the first water electrolysis machine act as a hydrogen booster for internal combustion engines. After a few years during the 1970's and 80's the Bulgarian inventor YULL Brown, patented and attempted to popularize Browns Gas as a cutting gas and fuel additive. During the 2000's there was a huge influx in Browns Gas devices coming to the mark, with many sensational claims of bringing dramatic reductions in fuel consumption and exhaust emissions in internal combustion engines.

The applications of HHO gas have been increased during the last ten year and now HHO gas has several applications in domestic areas and industrial area. All these application work on the same base with the same reactor but they differ in the pressure of produced gas and the rate of gas production.

1.2 common applications for HHO gas

- Can be used as fuel for diesel generators instead of diesel.
- Can be used for metal welding, cutting, and melting.
- Can be used for cooking instead of LPG gas.
- Can be used as carbon cleaner of car and internal combustion engines.
- Can be used as fuel for thermal station instead of fairness.

1.3 problem statement

The recently growth in industrial field makes the internal combustion engine and back up diesel generator more widely used than before. As a result for that the petroleum fuels (diesel, gasoline etc...) have been rapidly increased in consumption and the environment has been rapidly destroyed due to the harmful emission of fuel combustion e.g. ($CO2$, $NO2$, etc…). Also the household in Sudan especially in far states are suffering from lack in cooking gas (LPG) and the high cost of it. The high cost of (LPG) effect directly to the price of essential goods like bread and other essential requirement.

In our project we aim to design multi function HHO gas generator system which is able to serve all the previous application by controlling the gas pressure and amount of gas production. The system has interface unit to control the pressure and the rate of gas production and also have screens to monitor all the diagnostics parameter.

1.4 project deliverable and beneficiaries

By achieving this project we hope to have a multi function system to replace all types of fossil fuels in workshops and household as our developed system can be used easily with high safety standard for cooking and all domestic applications.

1.5 Objective

- Design the control circuit for the system by using classic control.
- Study the effect of temperature to the system performance.
- Make software by using excel to calculate operation parameters.

1.6 Methodology

- Study of all previous studies.

- Design model by using mechanical drawing.
- Design the prototype.
- Make lab test.
- Design software application.

1.5 Layout

This study consists of five chapters: Chapter One gives an introduction to the principles of the work, the problem statement and objectives. Chapter Two discuses the theoretical background of water electrolysis, and shows all the components used to build the system Chapter Three presents the system mathematical modeling, control design of all subsystem and the design considerations. Chapter Four deal with the practical model of the system and shows the experimental result. Finally, Chapter five provides the conclusions and recommendations.

CHAPTER TWO

Literature review

2.1 Historical background

The history of water electrolysis started as early as the first industrial revolution, in the year 1800, when Nicholson and Carlisle were the first to discover the ability of electrolytic water decomposing. By 1902 more than 400 industrial water electrolysis units were in operation and in 1939 the first large water electrolysis plant with a capacity of 10,000 Nm3 H2/h went into operation. In 1948, the first pressurized industrial electrolyser was manufactured by Zdansky/Lonza. In 1966, the first solid polymer electrolyte system (SPE) was built by General Electric, and in 1972 the first solid oxide water electrolysis unit was developed. The first advanced alkaline systems started in 1978. The history ends up in our days with the development of proton exchange membranes (PEM), usable for water electrolysis units and fuel cells, by DuPont and other manufacturers, due to the developments in the field of high temperature solid oxide technology and by the optimization and reconstruction of alkaline water electrolysers [1].

2.2 Methods of hydrogen production through water electrolysis

Despite the fact that the discovery of electrolytic water decomposing was first observed in acidic water, in industrial plants the alkaline medium is preferred, because corrosion is more easily controlled and cheaper construction materials can be used compared to acidic electrolysis technology. Other methods of hydrogen production, such as proton exchange membrane electrolysis, steam electrolysis have been developed in recent years. Hydrogen could also be generated as a byproduct during the chloralkali production. These technologies are briefly discussed in the next paragraphs [1].

2.2.1 Alkaline electrolysis

The principle of alkaline water electrolysis is schematically shown in figure (2.1) in the example of the monopolar arrangement electrolyser. Two molecules of water are reduced to one molecule of hydrogen and two hydroxyl ions at the cathode. The hydrogen escapes from the surface of the cathode recombined in a gaseous form and the hydroxyl ions migrate under the influence of the electrical field between cathode and anode through the porous diaphragm to the anode, where they are discharged to $\frac{1}{2}$ molecule of oxygen and one molecule of water. The oxygen recombines at the electrode surface and escapes as hydrogen does, as a gas. Whereas pressure less electrolysers are mainly built in the monopolar arrangement, which is the simplest construction principle, pressurized species are manufactured in the so-called bipolar filter press arrangement. The main reasons for the bipolar arrangement are the savings in space and in electrical bus bars and housing material, which are essential if large pressurized plants need to be built. A small disadvantage of the bipolar type when compared to the monopolar is the occurrence of shunt currents inside the electrolyte ducts of the bipolar electrolyser. In order to face this disadvantage, a more sophisticated design of the electrolyte and gas ducts and the application of a small protection current during operational shut-down times are necessary in bipolar water electrolysers. To meet the demands of the future energy market, in which electrolysers will have to serve as filling stations for vehicles in the environment of a town, rigorous reconstruction, optimization and safety implementation, is necessary [3].

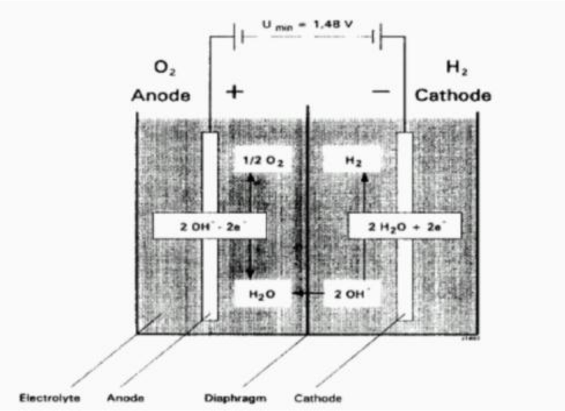


Figure (2.1): The principle of alkaline water electrolysis

2.2.2 Proton exchange membrane water electrolysis

The proton exchange membrane water electrolysis is based on the use of a polymeric proton exchange membrane as the solid electrolyte (polymer electrolyte membrane) and was first proposed by General Electric for fuel cell, and later, electrolyser applications. The proton exchange membrane electrolyser technology was developed by ABB (formerly Brown, Boveri Ltd), Switzerland, over the years from 1976 to 1989. The following advantages of polymer electrolyte technology over the alkaline one have been proposed

(i) Greater safety and reliability are expected since no caustic electrolyte is circulated in the cell stack.

(ii) Previous tests made on bare membranes demonstrated that some materials could sustain high differential pressure without damage and were efficient in preventing gas mixing.

(iii) The possibility of operating cells up to several amps per square centimeter with typical thickness of a few millimeters is theoretically afforded.

The technology has been demonstrated on a 100 kW commercial scale in two units: Stellram/ATEL (1987-1990 and 1991-present) unit and SWB, Solar-

Wasserstoff-Bayern-GmbH (1990-1996) unit. The operation of these two electrolysers has successfully demonstrated the feasibility of this technology for industrial hydrogen production. A major problem of electrolysers of this type is the limited lifetime of the electrolysis cells. Perfluorinated sulfuric acid membranes such as Nafion have been shown to be extremely resistant to the oxidative power of oxygen and even ozone evolving anodes. Nafion is a copolymer of tetrafluorethylene and a perfluorinated vinyl-ethersulfonyfluoride. This latter monomer gives rise to side chains with pendant sulfonic acid sites. The polymer morphology and the related properties of these membranes have been investigated in various applications, concluding that phase separation occurs in these polymers.

2.2.3 Wet and dry cell

In electrolysis, people have tried different ways to increase the output of Gas while decreasing the input of current. Some designs are more effective than others. Some people have tried to improve the conventional way, called ”wet system”, consisting on plates or tubes submerged in water, while others have tried a design called “dry cell” where the water run through the plate. Figure (2.2.a) and (2.2.b) shows the dry cell and wet cell.

Figure (2.2): a) The dry cell b) The wet cell

Dry cell designs are cheaper. This design can vary in shape or size, making in it very easy to install anywhere. The material used for the plates is stainless steel 316, and uses regular rubber O-rings to separate them. At the same time the amount of current input required to produce hydrogen is small. The wet system design consists in a more complicated manufactured process. This design is more expensive since the parts and the arrangement are more likely hard to produce. This system uses two different diameters of tubes in order to accommodate one inside the other one with different polarities, positive the inner and negative the outer. As a container, this kit uses a material capable to satisfy some important parameters. Resist higher temperatures, since the electrolysis process generates a significant amount of heat. The pressure built inside, sometimes up to 60 psi. And very important, it has to be a dielectric material in order to avoid electrolysis between the tubes and the inner wall of the container. The effectiveness of this system is higher than the dry cell system, although more current input is necessary the amount of hydrogen out is greater. Despite the cost of fabrication of this system and our limited budget we are choosing this design for our project in order to obtain a better production of hydrogen.

2.3 Overview of overall system

Our system consists of three subsystems pressure system, cooling system and the main reactor. Figure (2.3) shows the construction of the overall system.

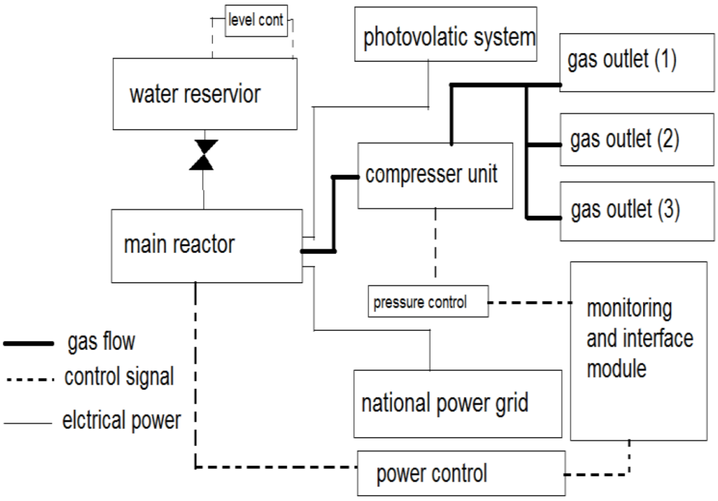


Figure (2.3): The construction of overall system

2.4 HHO gas generator

The main component in a Hydrogen-on-Demand system is the HHO or Hydroxy gas generator. This device can be a simple one cell unit or have as many cells as needed to produce the quantity of HHO gas desired. Electrolysis is the driving force for such generator. it separates chemically bonded compounds by passing an electric current through them. Another component used to produce HHO is an Electrolyte. Any substance containing free ions that behaves as an electrically conductive medium. Catalyst is the correct term because of the function it performs to speed up the production of HHO gas. Figure (2.4) shows gas generator.

Figure (2.4): The gas generator

2.5 The water reservoir

Its function to store the water to be analyzed before passing through the main reactor also the potassium hydroxide added to the water in this module. After the water pass the reactor It converted partially to HHO gas, this gas return back to the water reservoir carrying with it the remaining water to pass through the reactor again and the gas go to the bubbler as a final product. Figure (2.5) shows the water reservior.

Figure (2.5): The water reservoir

2.6 The electrolyte pump

It is used to circulate the water from the water reservoir to the main reactor, and it is also cooling the system and increase the rate of gas production. We used IWAKI magnetic drive raw water pump the model is (MD-30RT-115-NL) it is shown in figure (2.6) because it has many features as shown bellow

- Twin bearing system handle thrust loads, extends service life.
- Hollow rotating, internal cooling circuit reduces bearing temperature.
- Compact and quiet, energy efficient design.
- Totally enclosed.
- Tolerance to voltage variation without overheating.

Specifications

- Flow rate 600GPH.
- Maximum system pressure 11.6 PSI.
- Maximum current draw 0.4 amp at 220 volt.
- Motor speed 3150 r.p.m.
- Motor output $\frac{1}{16}$ HP.

Figure (2.6): Water pump model (MD-30RT-115-NL)

2.7 Temperature controller

used to adjust the inner ambient temperature of the system, when the temperature exceed a certain preset value the controller send signal to the relay to start two fans in order to cool the system and avoid any extra heat. And it is showm in figure **(2.7).**

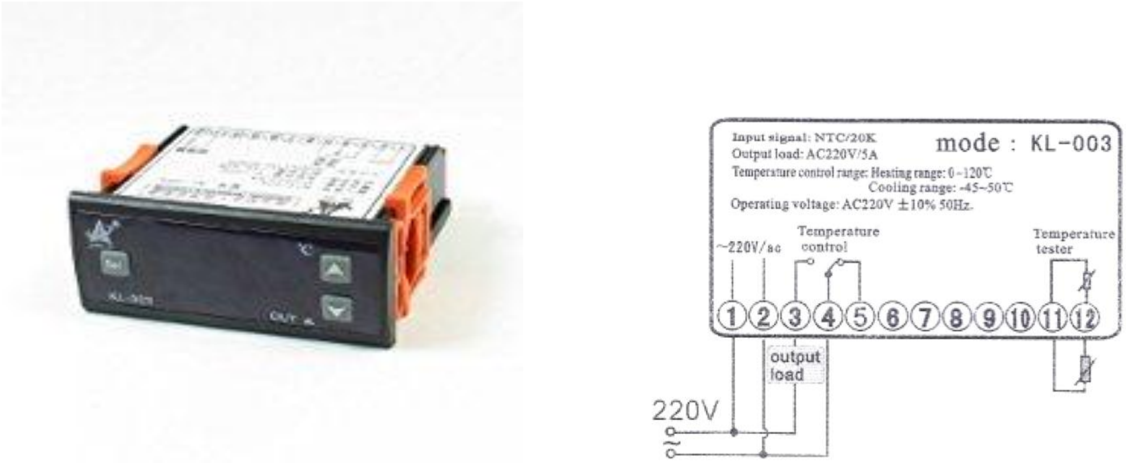


Figure (2.7): Temperature controller type (KL-003)

2.8 The pressure switch

Used to adjust the pressure in the system to 2 psi and when the gas pressure in the system reach this value the pressure switch turn off the electrolyser and stop gas production, when the users open the gas valve the pressure drop and the pressure switch turn on the reactor to start the gas production again. By using this technique the device introduce more than one option for more than one application. Figure (2.8) shows the pressure switch.

Figure (2.8): The pressure switch

2.9 The contactor

It is used to control the system operation. Start the system when start push button pressed and stop the system when stop push button pressed. The normal open contacts and normal close contacts used to control the water pump, the indicator lamps and the other elements of the system. Figure (2.9) shows 220V contactor.

Figure (2.9): 220V/AC contactor

2.10 The pressure gedge

To monitor the current pressure of the system and identify if the gas valve is open or closed by the user, the maximum range of the pressure valve is 350 mmHg.

2.11 The interface unit

It consists of start pushbutton and stop bush button to start and stop the system respectively. And also it consist two ON/OFF switches, the first one to control the water pump and the second one is to control the rate of gas production. The interface unit accompanied with monitoring system of ammeter and voltmeter to monitor the value of the current and volt also it has a temperature screen to monitor the temperature and also it consist of three lamps to monitor the current case of the system. Figure (2.10) shows the interface unit.

Figure (2.10): The interface unit

2.12 Flash Pot

It is used for safety purpose of the HHO Generator. It is made of Poly-vinyl chloride (PVC). Flash Port is a type of pressure release faucet. It blows off the extra   pressure during back fire. It consist springs which is placed inside the end cap As hydrogen flash back, glass ball pop-off and thus hydrogen releases from the space provided on the flash port into the surrounding environment and protect the device for bursting .Hence also known as safety guards.

2.13 Flash back arrester

This is another simple yet invaluable device designed to snuff out any flashback (backfire) from the torch. A majority of these devices are constructed of a tube gently packed with fine bronze wool and fitted with hose barbs on each end. Bronze wool is used because of its resistance to oxidation (rust). Figure (2.11.a) shows the flash pot and figure (2.11.b) shows the flash back arrester.

Figure (2.11): a) The flash pot b) The flash back arrestor

2.14 The bubbler

This is very important part in the HHO system and it has two main benefits

- It protects the system from a flashback (caused by backfire).
- It acts as a filter to clean the bubbles that are made by your generator, from unwanted particulates that may be present, depending on your chosen electrolyte and other factors.

The bubbler is simply a container half filled with water. HHO gas is fed to the bottom of the bubbler with a hose from your electrolyte tank and allowed to bubble through the water. The HHO gas continues through a hose from the top of the bubbler to the torch. The bubbler is provided with the flash pot to allow the top to pop off in the event of backfire.

Chapter three

Mathematical model

3.1 Sample of an Electrolyser Construction:

The electrolyser shown in Figure (3.1) is based on the common-duct series-cell electrolyser has about 80-90% total efficiency when all things are considered (ambient temperature, ambient pressure, accurate measurement of gas volume and current) when powered by straight DC. The electrolyser has 7 cells with a target input voltage of about 12.9-14.1Vdc depending on temperature. This makes the cell voltage about 1.85.

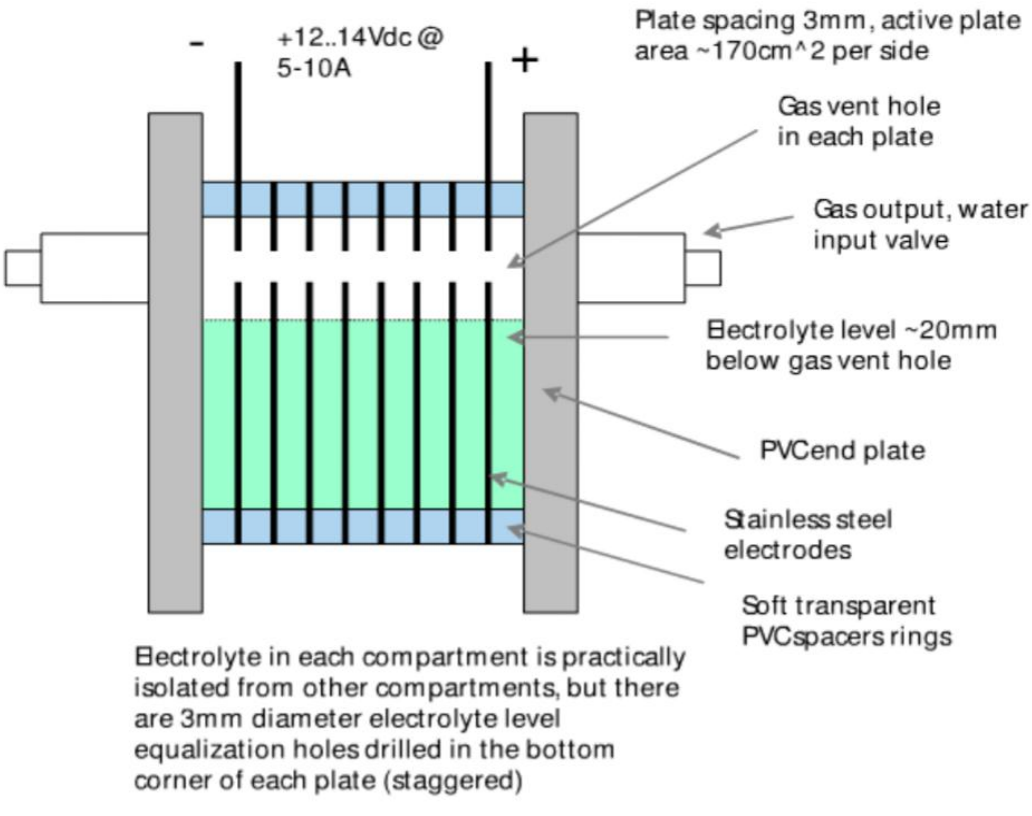


Figure (3.1): Electrolyser Construction

3.2 FUNDAMENTALS OF WATER ELECTROLYSIS

The principle of water electrolysis is to pass a direct current between two electrodes immersed in an electrolyte. Hydrogen is formed at the cathode and oxygen at the anode (positive terminal). The production of hydrogen is directly proportional to the current passing through the electrodes. More commonly, Michael Faraday's laws of electrolysis state that

i- The mass of a substance altered at an electrode during electrolysis is directly proportional to the quantity of electricity Q transferred.

ii- For a given quantity of electric charge Q, the mass of an elemental material altered at an electrode is directly proportional to the element's equivalent weight. The equivalent weight of a substance is equal to its molar mass divided by the change in oxidation state it undergoes upon electrolysis.

The electrodes should be resistant to corrosion, have a good electric conductivity, exhibit good catalytic properties and show a suitable structural integrity. Furthermore, the electrodes should not react with the electrolyte. The overall chemical reaction of water electrolysis without required thermodynamic energy values can be written as

$$\mathrm{H2O\ (l)} \rightarrow \mathrm{H2\ (g)} + \frac{1}{2}\mathrm{O2\ (g)} \tag{3.1}$$

Implementation of a diaphragm or separator is required to avoid recombination of the hydrogen and oxygen to preserve efficiency and safety. The electrodes, the separator, and the electrolyte form the electrolytic cell. Water electrolysers and fuel cells use similar technology, and the process in fuel cells is the reverse; hydrogen is converted into electricity and heat. In general, water electrolysers are more efficient than fuel cells

3.3 Thermodynamics

This mathematical model approach describes the thermodynamics relation with the reversible potential, thermo neutral voltage and taking into account the effect of temperature and pressure to the system also we take into account the effect of operational parameters current density and concentrations of (KOH) in the electrolyte .

By this mathematical model we study the relationship between cell parameters (operational parameters and structural parameters) and the efficiency of the system. MATLAB have been used to draw these equations and find out the most efficient condition which makes the system operate properly. We also want to use processor to control the pressure and temperature of the system in order to keep the cell operates at proper efficiency at all times. Also we add interface unit supplied with interface screens and switches for multi operation choices.

3.3.1 Thermodynamics calculation

The minimum work is required dissociation water is equal to Gibbs free energy is given by

$$\mathrm{GO} = \Delta \mathrm{H0} - \mathrm{T0}\Delta \mathrm{S} \tag{3.2}$$

The enthalpy change for the total reaction as shown

$$\Delta Ho = H(H2) + \frac{1}{2}\mathrm{H}(\mathrm{O2}) + \mathrm{H}(\mathrm{H2O}) \tag{3.3}$$

The entropy change for the total reaction as shown

$$\Delta So = S(H2) + \frac{1}{2}S(O2) - S(H2O) \tag{3.4}$$

The specific heat change for the total reaction as shown

$$\Delta Cp = CP(h2) + \frac{1}{2}CP(o2) - CP(h2o) \quad (3.5)$$

Table (3.1) shows the properties for reaction elements

Table (3.1): Properties for reaction elements

Properties	H2 (g)	O2 (g)	H2O (l)
Go(T0),**J mol−1**	-38960	-61120	-306690
Ho(T0) **J mol−1**	0	0	-285830
So(T0) **J mol−1k−1**	130.68	205.00	69.95
Cp , **J mol−1k−1**	27.28+0.00326*T +50000/T^2	29.96+0.00418*T -167000/T^2	75.44

By substituting the value from table in equation (2) and (3) we get

$$\Delta Ho = 285.84\ kj/mol$$

$$\Delta So = 0.16\ kj/mol.k$$

$$\Delta Ht = \Delta Ho + \int_{298}^{T} \Delta Cp.\Delta T$$

$$\Delta St = \Delta So + \int_{298}^{T} \frac{\Delta Cp}{T}.\Delta T$$

By substituting the value of Cp from the table in the above integration we get equation (5) and (6)

$$\Delta HT = 295367.673 - 33.18T + 2.675 \times 10^{-3}T^2 + 33500/T \quad (3.6)$$

$$\Delta ST = 349.612 + 5.35 \times 10^{-3}T - 33.18\ln T + 16750/T^2 \quad (3.7)$$

$$\Delta GT = 295367.67 - 382.792T - 2.675 \times 10^{-3}T^2 + 33.18T\ln T + 16750/T \quad (3.8)$$

Also we can calculate the reversible voltage between two plates by the following equation

$$Urev = \frac{\Delta GT}{nF} \qquad (3.9)$$

$$\mathrm{Urev(T)} = 1.5184 - 1.5421 \times 10^{-3}\mathrm{T} + 9.523 \times 10^{-5}\mathrm{T} + 9.84 \times 10^{-8}\mathrm{T} \qquad (3.10)$$

Where:

N= 2 F=faraday constant (96485.3365 C/mol)

3.4 Definition

- **The reversible voltage**
  It is the minimum voltage between two plates which can make production

Also we can obtain thermo neutral voltage by this equation [3].

$$\mathbf{Ut.n} = \frac{\mathbf{\Delta Ht}}{\mathbf{nF}} \qquad (3.11)$$

$$Utn = 1.5306 - 1.7194 \times 10^{-4}T + 1.3862 \times 10^{-8}T^2 + \frac{0.1736}{T} \qquad (3.12)$$

- **Thermo neutral voltage**
  It is the voltage which makes the production occurs without any heat absorption or heat production [3].
  Figure (3.2) gives the relation between the temperature in (c) and the volt.

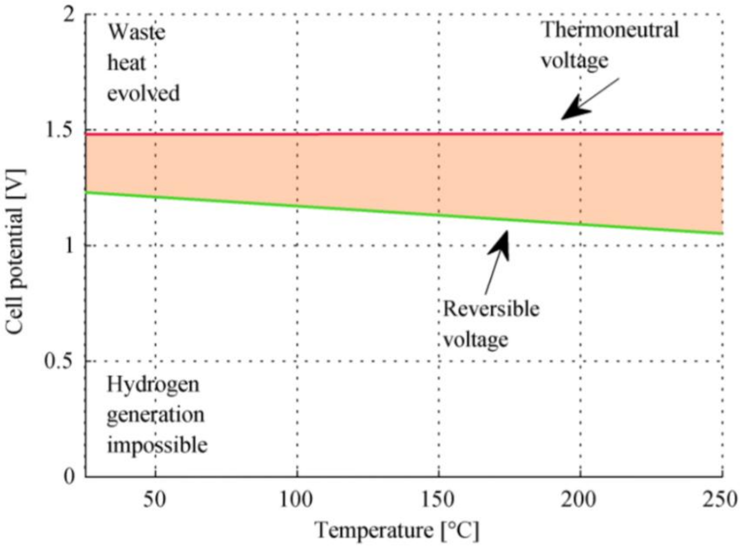


Figure (3.2): The relation between temperature in C^{O} and volt

3.5 Efficiency calculation

The efficiency is affected directly by the losses which occur during the electrolysis process and is defined as polarization losses. The polarization further more can be divided into the activation losses at anode and cathode, Ohmic losses by conductivity of electrolyte.

The efficiency is given by equation (3.13)

$$\eta E = \frac{\mathrm{UHHV}}{Ucell} \tag{3.13}$$

Where:

UHHV = higher-heating-value-voltage

Ucell = the total cell voltage

$$U\mathrm{HHV} = 1.4756+2.252\cdot 10^{-4}T + 1.52\cdot 10^{-8}T^{2} \tag{3.14}$$

T= temperature in Celsius

Ucell = Urev +Uohm +Uact

Uact= $\alpha c + \alpha a$

$$\text{Uact}=\frac{2.303RT}{nF}\left(\frac{1}{\alpha a}+\frac{1}{\alpha c}\right)\ln\frac{i}{i0} \tag{3.15}$$

Where:

$$\alpha c = 0.1175 + 0.00095(T - 273) \tag{3.16}$$

$$\alpha a = 0.0675 + 0.00095(\text{T} - 273) \tag{3.17}$$

$$\eta\text{E} = \frac{1.4756+2.252\cdot 10-4\text{T} + 1.52\cdot 10-8\text{T}2}{\text{Urev}+\frac{2.303RT}{nF}\left(\frac{1}{\alpha a}+\frac{1}{\alpha c}\right)\ln\frac{i}{i0}+0.09\text{I}} \tag{3.18}$$

3.6 Mass flow rate calculation

$$V(H2) = \frac{I.M(H2)}{2F\rho(H2)}$$

$$V(O2) = \frac{I.M(O2)}{4F\rho(O2)}$$

$\rho H2$ = Density of hydrogen molecule, (0.0899 kg m^{-3})

$\rho O2$ = Density of oxygen molecule, (1.429 kg m^{-3})

The total volume of hydroxyl gas is given by equation (3.19)

$$\text{VT} = (\text{VH2} + \text{VO2}) \times 3600 \times 1000 \text{ in lt/hr} \tag{3.19}$$

Quantity of heat produced in the cell

$QJ = I(\alpha c + \alpha a + VOHM)$

3.7 Design consideration

To ensure the system is operating in its optimum conditions a lot of consideration have been taken for, for the pressure system the vapor pressure of the water have been calculated and for the cooling system the heat added by the cell during the operation have been calculated.

3.7.1 The pressure system

Vapor pressure is the pressure exerted by a pure component at equilibrium, at any temperature, when both liquid and vapor phases exist. The pressure system has been designed for maximum pressure equal to the vapor pressure. Vapor pressure can be calculated from the Antoine equation. By using Table (3.2) which shows the Antoine equation parameters

$$\log p* = A - \frac{\mathrm{B}}{T+C}$$

Where p* is the vapour pressure of a pure component.

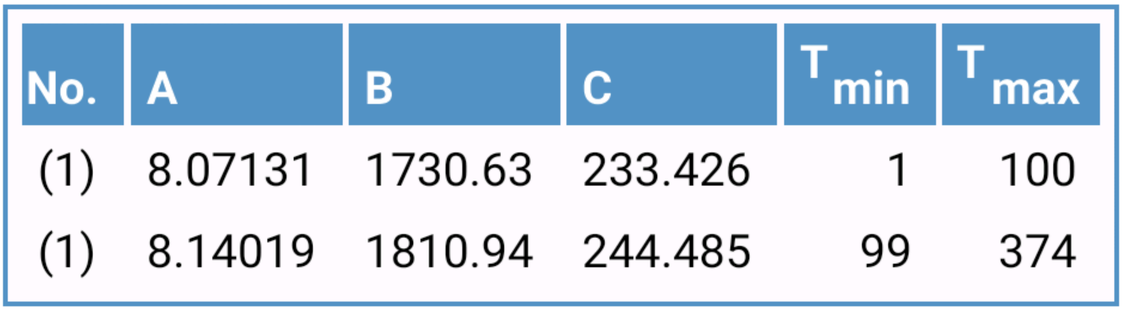
A, B, and C are the Antoine constants.

By using Dortmund data bank (DDB) simulator the following results have been obtained and the results from the software screen as shown bellow.

Component details

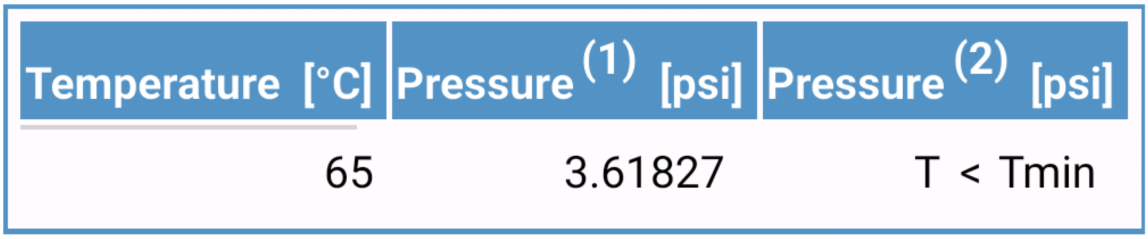
#DDB	Name	CAS-No.	Formula
174	Water	7732-18-5	H2O

Table (3.2): Antoine equation parameters (P IN mmHg, T in C^{O})



No.	A	B	C	T min	T max
(1)	8.07131	1730.63	233.426	1	100
(1)	8.14019	1810.94	244.485	99	374

Calculations for given temperature (65C^{O})



Temperature [°C]	Pressure $^{(1)}$ [psi]	Pressure $^{(2)}$ [psi]
65	3.61827	T < Tmin

The temperature of the reactor under operation is 65 C^{O} and by using this temperature in (DDB) simulator we get a vapor pressure equal to 3.61827 psi as shown above.

The pressure switch is adjusted to 3.5 psi so that the switch can turn off the reactor above the calculated value of vapor pressure. Figure (3.3) shows the relation between pressure and temperature

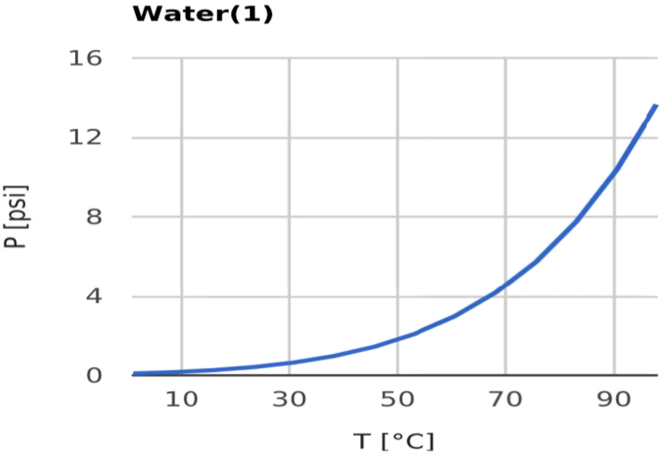


Figure (3.3): The relation between pressure and temperature

The pressure system control circuit consists of normal open point and normal close point, the normal close stop the system when the pressure reaches 2psi. Figure (3.4) shows the control circuit of pressure system.

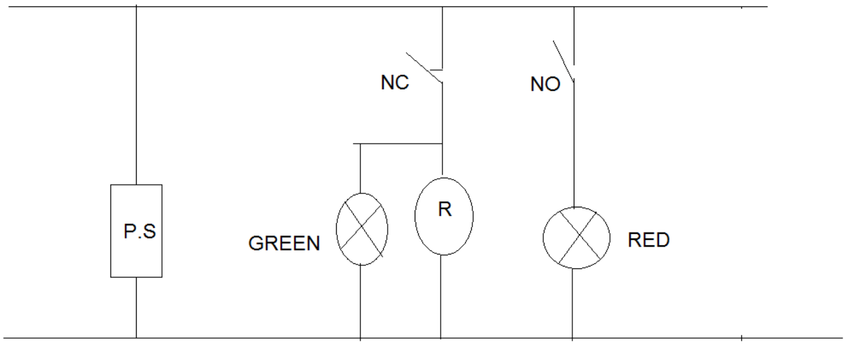


Figure (3.4): The control circuit of pressure system

The green lamb indicates that the reactor is under operation and the pressure is now increasing, the red lamb indicates that the reactor is now turned off and the pressure in the system exceeds the equilibrium pressure of 3.5psi.

3.7.2 The main reactor

The reactor has been designed by using the stainless steel 304 because it is very resistive for corrosion under the situation of the electrolysis. We design the plates in square shapes (25cm×25cm) consist of two holes for water input and gas output.

a) Calculating the reversible voltage
   Under $45C^{o}$ of temperature we can find the suitable value of reversible voltage by using equation (3.10) as shown bellow

$$Urev = 1.5306 - 1.7194 \times 10^{4} \times (45 + 273) + 1.3862 \times 10^{-8} \times (45 + 273)^{2} + \frac{0.1736}{75 + 273}) = 1.47V$$

b) Calculating the thermo neutral voltage
   Under $45C^{o}$ of temperature we can find the suitable value of thermo nutral voltage by using equation (3.12) as shown bellow

$$Utn = 1.5306 - 1.7194 \times 10^{-4} \times (45 + 273) + 1.3862 \times 10^{-8} \times (45 + 273)^2 + \frac{0.1736}{(45 + 273)} = 1.5311\,V$$

To make the cell able to operate with 220 volt by its optimum efficiency the voltage should be greater than thermo neutral voltage by desirable value so 110 plates have been used to divide the voltage to give reversible voltage greater than thermo neutral voltage

$$Urev = \frac{total\ voltage}{number\ of\ series\ plates} = \frac{205}{110} = 2\ volt$$

The reactor of 110 plates gives reversible voltage of 2 volt and this is very close to the optimum value of thermo neutral voltage so the system will operate in healthy conditions.

The main control unit for the reactor is the contactor, it starts the system when press start push button and stop it with stop push button. Figure (3.5) shows the control circuit of the main reactor

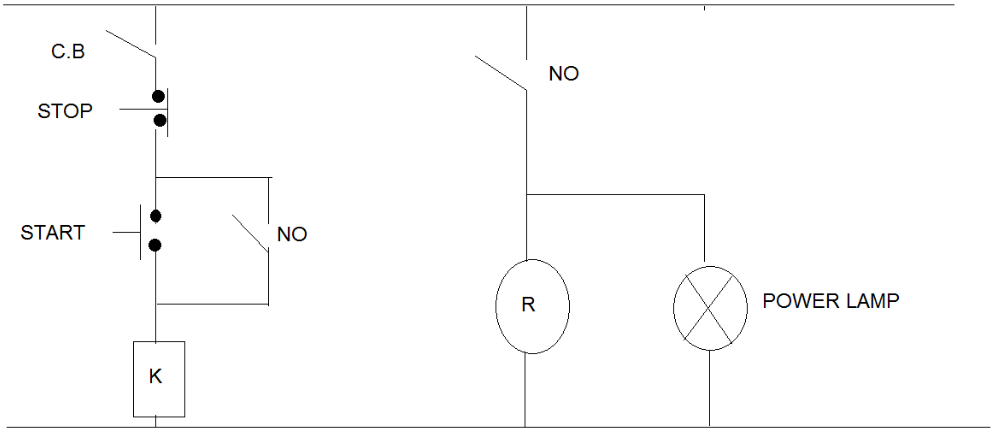


Figure (3.5): The control circuit of the main reactor

3.7.3 Cooling system

The heat inside the case of system is equal to the ambient temperature plus the heat added during the operation. Any additional temperature is cooled by two fans mounted to the case of the system.

The heat added by the cell during the operation can be calculated as shown bellow

QJ = I(Uact + $VOHM$)

Uact =$\frac{2.303RT}{nF}(\frac{1}{\alpha a}+\frac{1}{\alpha c})\ln\frac{i}{i0}$ =

$$Vohm = j\frac{tmem}{\alpha mem}$$

where tmem t is the membrane thickness and

$$\alpha mem = (0.005139\lambda mem - \ 0.003260)exp[1268(\frac{1}{303}-\frac{1}{T})]$$

As our system works in full humidity conditions so λmem = 14.003

$\alpha mem = (0.005139 \times 14.003 - \ 0.003260)exp[1268(\frac{1}{303}-\frac{1}{(65+293.15)})]$ = 0.05969

$Vohm = j\frac{0.9\times10^{-3}}{0.0596}$= 0.015078×5= 0.29845V

Vact=1.6425V

QJ = 5× (1.6425 +0.29845)= 9.704 KJ

= 5.11C^{o}

The total temperature = 5.11+40=45

We adjust the temperature sensor to turn on the fans when the temperature exceed 48C ^{0}. The control circuit of the cooling system shown in figure (3.6)

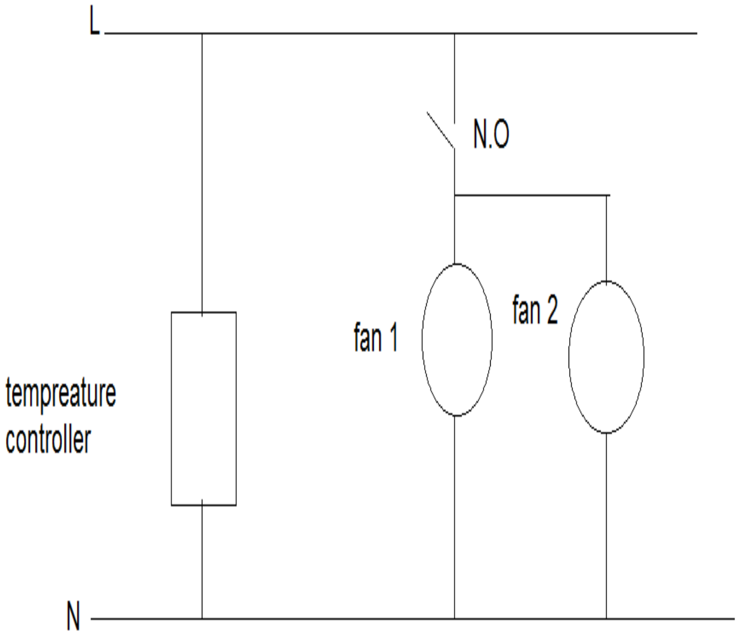


Figure (3.6): Control circuit of the cooling system

CHAPTER FOUR

EXPERIMENTS AND RESULTS

4.1 Measurement of reversible voltage and thermonutral voltage

Water electrolyser systems have auxiliary equipment, which enable the automatic production of electrolytic hydrogen. Generally, water electrolyser systems comprise pressure system, cooling system , interface unit and block of gas production -the main reactor. The complete system of alkaline electrolysis is illustrated in figure(4.1) and (4.2).

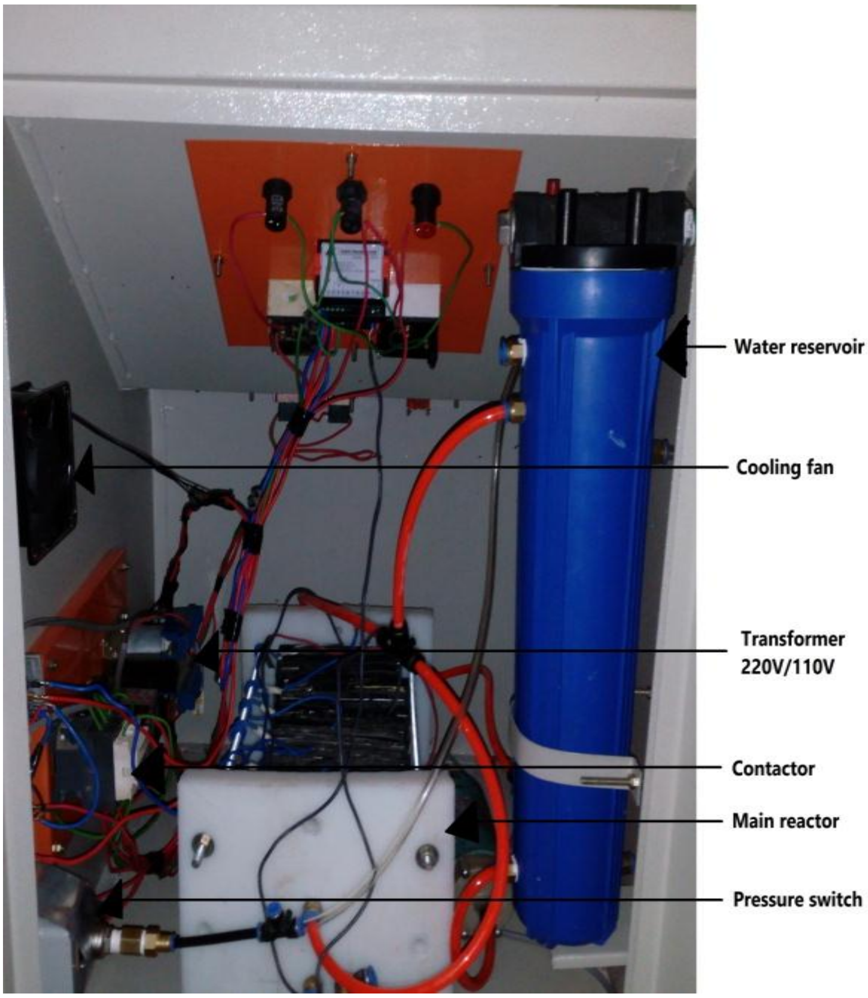


Figure (4.1): Inside the system of alkaline electrolyser

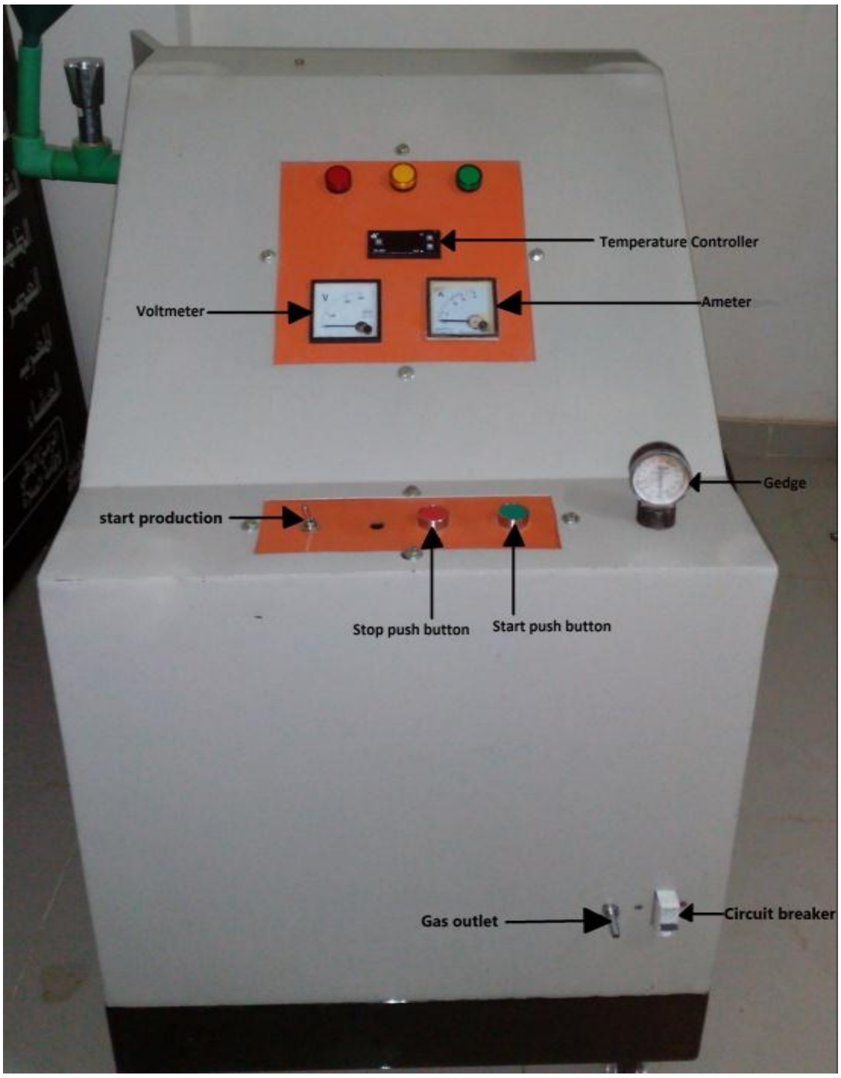


Figure (4.2): Outside the system of alkaline electrolyser

The setup of one block of the reacter is shown in Figure (4.3).110 plates connected to make up one block giving one gasproducing block. The block’s electrical connections are on the ends of the reactor to form two stacks. In every time the electrode with no electrical connection are called nutral plates as there is no voltage connected to them and the others are called power plate. The potential is divided between the neutral plates according to voltage division in series connections.

The votage between two neutral plates (reversible voltage) have been measured . Also the reversible voltage and thermonutral voltage have been calucated form equation (3.10) and (3.12) respectively and the result written in table (4.1) and tabel (4.2) with different concenteration of (KOH) also the heat added by the system during different times of operation have been measured with the temprature controller.

Figure (4.3) : The electerical connection

4.1.1 results with 30g of KOH for one litter of water

the value of tempreature and reversible voltage during one hour with concenteration of 30g of KOH have been measured and calculated. Table (4.1) shows the obtained results.

Table (4.2) the value of tempreature and reversible voltage with 100g of KOH

Time (min)	Tempreature (C^o)	Measured reversible votage (V)	Claculated reversible voltage (V)	Calculated Thermonutral voltage (V)	Current (A)
0	45	2.130	2.100	1.477	5A
1:56	46	2.130	2.102	1.477	
4:44	47	2.110	2.102	1.477	
7:36	48	2.105	2.102	1.477	
12:50	49	2.069	2.103	1.477	
17:51	50	2.060	2.101	1.477	
24:44	51	2.102	2.098	1.477	
30:47	52	2.096	2.096	1.476	
34:55	53	2.094	2.093	1.476	
41:45	54	2.092	2.090	1.476	
51:04	56	2.080	2.084	1.476	

4.1.2 results with 100g of KOH for one litter of water

Table (4.2) the value of tempreature and reversible voltage during 20 minutes with concenteration of 100g of KOH

Table (4.2) the value of tempreature and reversible voltage with 100g of KOH

Time (min)	Tempreature (C^o)	Measured reversible votage (V)	Claculated reversible voltage (V)	Calculated thermonuetral voltage (V)	Current (A)
2:00	45	2.130	2.100	1.477	9.8A
6:40	46	2.130	2.102	1.477	
8:25	47	2.110	2.102	1.477	
10:16	48	2.105	2.102	1.477	
12:00	49	2.069	2.103	1.477	
13:45	50	2.060	2.101	1.477	
15:18	51	2.102	2.098	1.477	
16:53	52	2.096	2.096	1.476	
18:30	53	2.094	2.093	1.476	

4.2 The relation between temprature and reversible voltage

the relation between reversible voltage and tempreature have been ploted with MATLAB as show in figeure (4.4). and the code is shown in appendix (A).

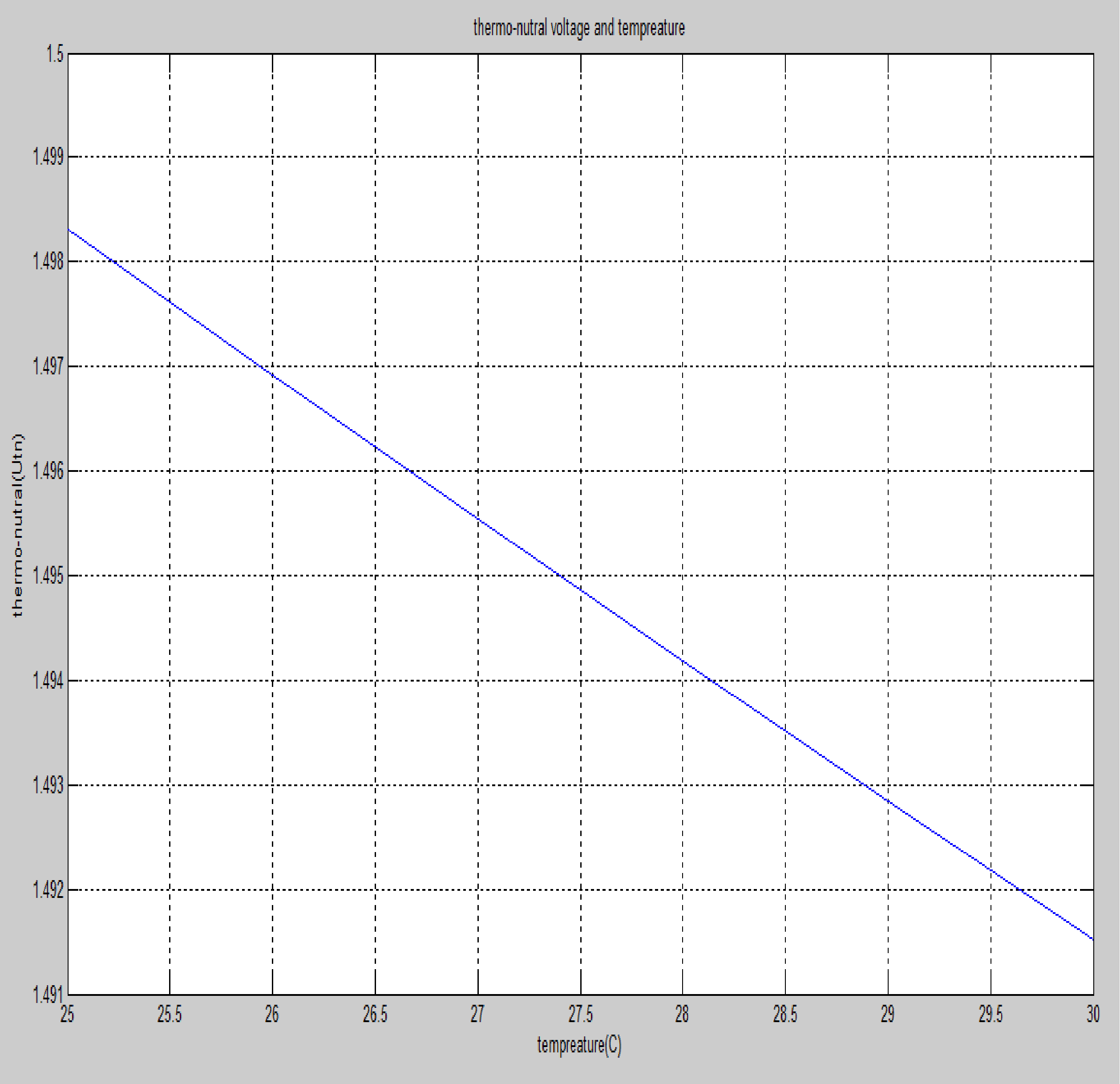


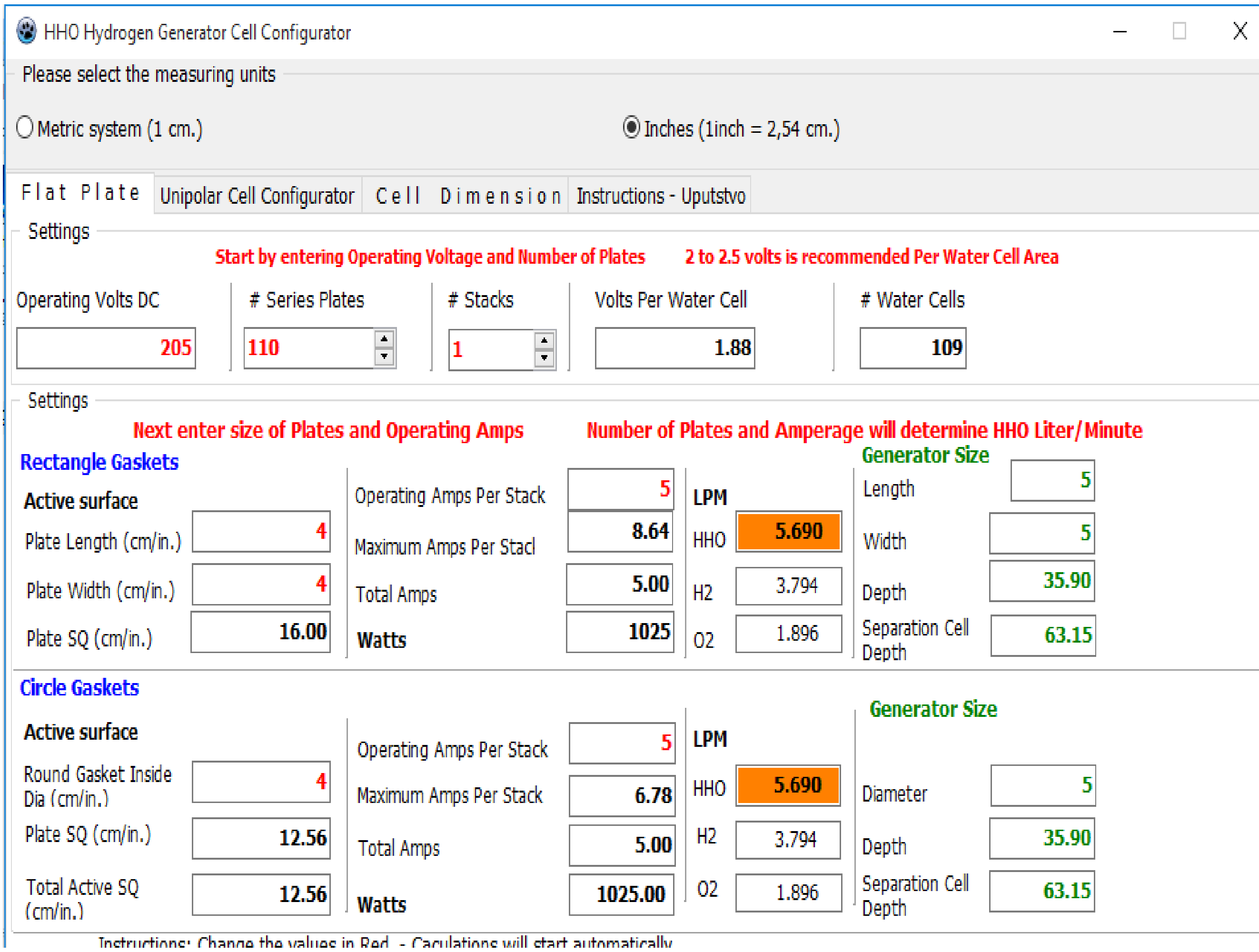
Figure (4.4): the relation between reversible voltage and tempreature

4.3 The results from HHO calculator software

The HHO calculator have been designed to show the variables affect HHO gas production and help to choose the size of the cell which is capable to produce the LPM which is desired by the designer.

4.3.1 Results with 30g of KOH for 1 litter of H_2O

Figure (4.5) show the value of rate of production and the dimensions of the main reactor according to the length and width of the plate with concentration of 30g of KOH for one litter of water.



Please select the measuring units

○ Metric system (1 cm.)
● Inches (1inch = 2,54 cm.)

Settings

Start by entering Operating Voltage and Number of Plates

2 to 2.5 volts is recommended Per Water Cell Area

Operating Volts DC: 205
Series Plates: 110
Stacks: 1
Volts Per Water Cell: 1.88
Water Cells: 109

Settings

Next enter size of Plates and Operating Amps

Number of Plates and Amperage will determine HHO Liter/Minute

Rectangle Gaskets

Active surface
Plate Length (cm/in.): 4
Plate Width (cm/in.): 4
Plate SQ (cm/in.): 16.00

Operating Amps Per Stack: 5
Maximum Amps Per Stacl: 8.64
Total Amps: 5.00
Watts: 1025

LPM
HHO: 5.690
H2: 3.794
O2: 1.896

Generator Size
Length: 5
Width: 5
Depth: 35.90
Separation Cell Depth: 63.15

Circle Gaskets

Active surface
Round Gasket Inside Dia (cm/in.): 4
Plate SQ (cm/in.): 12.56
Total Active SQ (cm/in.): 12.56

Operating Amps Per Stack: 5
Maximum Amps Per Stack: 6.78
Total Amps: 5.00
Watts: 1025.00

LPM
HHO: 5.690
H2: 3.794
O2: 1.896

Generator Size
Diameter: 5
Depth: 35.90
Separation Cell Depth: 63.15

Instructions: Change the values in Red - Caculations will start automatically

Figure (4.5) The HHO calculator results with concentration of 30g of KOH

4.3.2 Results with 100g of KOH for 1 litter of H_2O

Figure (4.6) show the value of rate of production and the dimensions of the main reactor according to the length and width of the plate with concentration of 100g of KOH for one litter of water.

Please select the measuring units

● Metric system (1 cm.)
○ Inches (1inch = 2,54 cm.)

Settings

Start by entering Operating Voltage and Number of Plates
2 to 2.5 volts is recommended Per Water Cell Area

Operating Volts DC	# Series Plates	# Stacks	Volts Per Water Cell	# Water Cells
205	110	1	1.88	109

Settings

Next enter size of Plates and Operating Amps
Number of Plates and Amperage will determine HHO Liter/Minute

Rectangle Gaskets

Active surface

Plate Length (cm/in.): 15
Plate Width (cm/in.): 15
Plate SQ (cm/in.): 225.00
Operating Amps Per Stack: 9.8
Maximum Amps Per Stacl: 18.83
Total Amps: 9.80
Watts: 2009.00

LPM
HHO: 11.152
H2: 7.437
O2: 3.715

Generator Size
Length: 16
Width: 16
Depth: 35.90
Separation Cell Depth: 63.15

Circle Gaskets

Active surface

Round Gasket Inside Dia (cm/in.): 4
Plate SQ (cm/in.): 12.56
Total Active SQ (cm/in.): 12.56
Operating Amps Per Stack: 5
Maximum Amps Per Stack: 1.05
Total Amps: 5.00
Watts: 1025.00

LPM
HHO: 5.690
H2: 3.794
O2: 1.896

Generator Size
Diameter: 5
Depth: 35.90
Separation Cell Depth: 63.15

Figure (4.6) The HHO calculator results with concentration of 100g of KOH

Chapter five

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This study investigates the design consideration for cooling system, pressure system and the main reactor.

One of the best chemical substances added to water is Potassium Hydroxide which acts as a catalyst in the process of electrolysis in that it promotes the gas production but is not used up in the process. It is a strong and pure electrolyte .It gives 95 - 100% pure HHO gas production along with the right generator design.

From the experimental results we expected that 30-50 grams of KOH/liter is where the electrolytic dissociation is allowing the most electrical conductivity, and the high current can follow without causing large amount of heat.

Form experimental results we found that as the temperature increase the reversible voltage decrease and the change in temperature reduce as the time of operation increase until it reaches the equilibrium temperature and at this moment the reversible voltage remain constant and the rate of production reach its highest value.

5.2 Recommendations

- Due to lack of modern experimental devices, we could not manage to make more experiments on the system.
- We recommended that to study the HHO system with the thermal power stations and other internal combustion engine.

- In this project the designed HHO generator system is suitable for cutting welding and cooking but also it can be used to reduce fuel consumption and emissions, in the internal combustion engine.

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2- LaBella’s Auto Repair, **"HHO Hydrogen Generator Dry Fuel Cell Installation Manual Instructions Presented by",** **http://labellasautorepair.com**, 2642 Delaware Ave Kenner, Louisiana 70062 504 469 9986, 2008.

3- Timothy limplan, **"An Overview of Hydrogen Production and Storage Systems with Renewable Hydrogen Case Studies",** Oakland, California 2011**.**

4- Uhanu kiran, Y.V.Ramana murty, **"Mathematical Modelling and Simulation Analysis of Alkaline Water Electrolyser for Stationary Electrolyte in Atmospheric Pressure".** International Journal of Mechanical Engineering and Computer Applications, Vol 3, Issue 5, 2015.

5- Renao, Christian, et al, **"Simulation tool based on a physics model and an electrical analogy for an alkaline electrolyser."** Journal of Power Sources 250 (2014): 58-67, 2014.

APPENDIX A

MATLAB code for the HHO system modeling

```
clear all; close all; clc;
F = 96485;
R = 8.3144621;
m = 7.64;
z = 2;
M = 8;
i = 0:0.01:0.5;
ilim = 30;
p = 30;
pw = p*0.986923267;
t = 75;
T=t + 273.15;
TP = 0:0.01:(t + 273.15);
pKOH = exp(0.01621 - 0.138*m + 0.1933*m^0.5 + 1.024.*log(pw))
Urev1 = 1.5184 - 1.5421e-3.*T + 9.523e-5.*T.*log(T) + 9.84e-8.*T.^2
Urev = Urev1 + 4.309e-5.*T.*log(((p-pKOH).^1.5.*pw)./pKOH);
alpha_a = 0.0675 + 0.00095.*T;
alpha_b = 0.1175 + 0.00095.*T;
i0 = 3.15e-4
Uact_a = 2.306*R.*T./(z*F.*alpha_a)*log10(i./i0);
Uact_b = 2.306*R.*T./(z*F.*alpha_b)*log10(i./i0);
Uact = Uact_a + Uact_b;
delta = 0.66;
sigma = -2.041*M - 0.0028*M^2 + 0.001043*M^3 + 0.005332*M.*T +
207.2*M./T - 0.0000003*M^2.*T.^2
eps = 0.0153*(i./ilim).^0.3;
sigma_eps = (1-eps).^1.5*sigma;
r = delta./sigma_eps;
Uohm = r.*i;
Ucell = Urev + Uact + Uohm;
 t=0:0.1:75;
 x=1.4756+2.252*10^-4.*t+1.52*10^-8*t.^2;
 plot(t,x)
 xlabel('tempreature')
 ylabel('UHHV')
 title('higher heating value voltage')
 x=25:1:30;
```

```
z=1.5306-1.9836*10^-3.*x-1.3862*10^-8.*x.^2+1.7194*10^-
4.*x.*log(x)+0.0868.*x.^-1;
plot(x,z)
ylabel('thermo-nutral(Utn)')
xlabel('tempreature(C)')
title('thermo-nutral voltage and tempreature')
```

APPENDIX B

The validity range of vapor pressure for different temperatures

Temperature [°C]	Pressure (1) [psi]	Pressure (2) [psi]
1	0.0944668	T < Tmin
8.46	0.159573	T < Tmin
15.92	0.261227	T < Tmin
23.38	0.415564	T < Tmin
30.84	0.643985	T < Tmin
38.3	0.974244	T < Tmin
45.76	1.44162	T < Tmin
53.22	2.09015	T < Tmin
60.68	2.97385	T < Tmin
68.14	4.158	T < Tmin
75.6	5.72033	T < Tmin
83.06	7.75223	T < Tmin
90.52	10.3598	T < Tmin
97.98	13.665	T < Tmin
105.44	T > Tmax	17.8382
112.9	T > Tmax	22.8759
120.36	T > Tmax	29.0393
127.82	T > Tmax	36.5127
135.28	T > Tmax	45.4981
142.74	T > Tmax	56.2162
150.2	T > Tmax	68.906
157.66	T > Tmax	83.8248
165.12	T > Tmax	101.248
172.58	T > Tmax	121.47
180.04	T > Tmax	144.801